LOCATING THE SOURCE OF AN UNKNOWN SIGNAL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method and apparatus for locating the source of an unknown signal received by a plurality of signal relays.

2. Discussion of the Invention

Prior art location systems are known which employ a technique based on determination of the time difference of arrival (TDOA) of two signals from the source to be located, ie an unknown transmitter. In this technique, a signal from the transmitter is relayed to a ground-based receiving station along two independent signal paths by a respective earth-orbiting satellite in each path. Each satellite incorporates a transponder system which accepts a signal (uplink) from a ground transmitter at one frequency and returns a frequency-shifted (downlink) signal to a ground receiver with the aid of a turnround oscillator. The signal paths are of unequal length, because the two satellites are in different positions. In consequence, the signal arrival time at the receiving station associated with one path is different to that associated with the other. The positions of the two satellites and the receiving station are known, and consequently the time difference of arrival—the TDOA—of the signal over the two different paths provides information on the location of the unknown transmitter.

For specific satellite positions, the locus of points of constant TDOA defines a curve on the earth referred to as a line of position (LOP). An unknown ground-based transmitter giving rise to a specific value of TDOA is located at some point on the LOP associated with that value. The geometrical relationship between the satellites together with signal propagation delay in satellite transponders and receiving station equipment, must be known in order to determine the correct value of TDOA.

However, an LOP only locates an unknown transmitter to an arbitrary position on a curve. U.S. Pat. No 5,008,679 discloses a transmitter location system incorporating two relay satellites as previously mentioned, the system employing both the TDOA of signals from an unknown transmitter and what is referred to as their frequency difference of arrival (FDOA). FDOA occurs because the relay satellites are in motion relative to the earth and to one another, and in each case the motion introduces a Doppler shift into the downlink signal frequency. The two satellites' Doppler shifts differ, and this produces a frequency difference or EDOA between signals arriving at the receiving station from respective satellites. As in the TDOA approach, an FDOA measurement defines a line of position (LOP) upon which the unknown transmitter lies. The TDOA and FDOA lines of position generally differ, and their intersection provides the location of the unknown transmitter.

However, the system of U.S. Pat. No. 5,008,679 is subject to a number of constraints. It requires the positions and velocities of the satellites to be known with a high degree of accuracy. It cannot be used effectively with communications signals of 50 kHz bandwidth or less if the satellites have orbital inclinations of more than 0.1 degree relative to the Earth's equatorial plane. The system also requires a very high degree of phase stability from the ground station local oscillators and the satellite signal turnround oscillators. The latter requirement may render the system ineffective with satellites having very low inclination angles, ie less than 0.01 degree; this is because the Doppler shift caused by satellite motion is small and difficult to measure at such inclinations.

Furthermore the system of U.S. Pat. No. 5,008,679 can only be used with collocated receiving ground stations which have common time and frequency reference sources. It cannot be used without modification where the receiving ground stations are geographically separate. The system also requires the use of phase-locked frequency downconversion chains.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an alternative form of transmitter location system.

The present invention provides a method of locating the source of an unknown signal received by a plurality of signal relays, the method including the steps of:

(a) arranging for a plurality of receivers to receive the unknown signal from respective signal relays;

(b) arranging for the receivers to receive respective reference signals from respective signal relays, the reference signals either being replicas of a single signal or being replicas of signals locked in frequency, time and phase to a single signal and the reference signals being transmitted to the signal relays from reference transmitting means of known location;

(c) processing the respective unknown signal and reference signal received by each receiver coherently such that these signals preserve their timing and phase information relative to one another;

(d) performing cross ambiguity function processing of the processed reference signals and the processed unknown signals and employing the reference signals to counteract phase noise and frequency drift effects in the unknown signals in order to determine at least one of the following:

(i) values of the Differential Time Offset (DTO) and Differential Frequency Offset (DFO) of the unknown signals,

(ii) values of the DTO of the unknown signals corresponding to different signal relay positions,

(iii) values of the DFO of the unknown signals corresponding to different signal relay positions,

(iv) values of the DTO of the unknown signals corresponding to different combinations of signal relays,

(v) values of the DFO of the unknown signals corresponding to different combinations of signal relays,

(e) calculating the position of the unknown signal source from the values of DTO and/or DFO as the case may be determined in Step(d).

The invention provides the advantage that it does not require the positions and velocities of the satellites to be known with the degree of accuracy required in the prior art, and it can be used with satellites which have an orbital inclination of up to at least 3 degrees. The invention does not require the degree of relay or receiver phase stability required in the prior art. It does not require receivers which are located geographically together, which have common time and frequency references and which employ phase-locked frequency downconversion using a common precision frequency standard. The invention is also able to perform location of an unknown signal source in the presence of other unwanted signals.

Processing in Step (c) of the invention is preferably carried out in respect of signals received by each receiver by downconverting the unknown signal and the reference signal to intermediate frequency (IF) signals with predetermined bandwidths and obtaining digital samples thereof with sample timing and frequency downconversion controlled in